MODIS Level 1B QA Plan

Version 1.2

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1. Introduction

The MODIS L1B QA Plan is intended to cover activities needed to assure a high quality level 1B data product that do not fall within the pre-launch instrument calibration [*Zukowski et al.*, 1995], the operational calibration of the instrument [*Jones et al.*, 1995], or the validation of the science data product [*Barbieri*, 1996].

The calibration provides the method used to convert raw instrument counts to radiance and reflectance products. The validation assesses the accuracy, precision, and resolution of the data product [*Salomonson*, 1994]. The QA Plan specifies procedures used to verify that the instrument has operated in the expected manner, that the calibration algorithms are appropriate for the instrument and the data they process, and that the input data has the characteristics expected by the algorithms.

1.1. Scope

There are five specific areas that will be considered as part of the MODIS L1B QA Plan. They are the L1B production QA flags, the L1B production QA metadata, analysis of the engineering data, consistency tests, and analysis tools.

Parts of this QA analysis will take place within the L1B operational code. Parts will occur in the TLCF. It is critical to accurately identify the operations of data extraction and statistical analysis that will occur in the L1B code in a timely fashion because of the tight schedule leading to Version 2 code delivery and subsequent infrequent opportunities for change.

1.1.1. L1B Production QA Flags

During normal MODIS L1B processing a series of tests are conducted to verify that the data and instrument state are behaving in a nominal fashion. When these tests detect that something is not nominal then one or more flags will be set in the output data stream. Each flag is a binary value, True or False. Some of these flags indicate serious problems with the resultant data and some indicate conditions that are not known to corrupt the results but are nonstandard in some fashion. Details of the flags and processing can be found in section 2.

1.1.2. L1B Production QA Metadata

Each MODIS L1B granule will incorporate numeric summary information derived from tests made during the processing of that granule. Examples of this type of information are the total number of missing observations in the granule or the number of saturated observations. Details of the L1B production QA metadata are in section 3

1.1.3. Engineering Data

The MODIS telemetry stream contains hundreds of measurements of internal instrument state. These include temperatures, voltages, times, currents, and other instrument parameters. These values will be monitored for values exceeding normal ranges and statistical deviations from expected patterns. This engineering data value testing and monitoring is intended for data quality purposes. For these purposes we are using engineering data in the sense used in [*Mehrten*, 1996]. Instrument health and safety monitoring is controlled by flight operations and described in the MODIS Flight Operations Monitoring Plan [*Knight and Parker*, 1996]. The QA tests and collected statistics are described in section 0.

1.1.4. Trending and Consistency Analysis

The MODIS instrument and project are a complex system with intentional redundancy and stability. When multiple techniques exist to determine the same or related quantities we choose the most reliable for calibration. The other techniques can be evaluated for consistency. Nominally stable behavior can be tested for temporal changes. These tests provide a level of protection against large classes of errors. The trending and analysis tests are described in section 5.

1.1.5. Analysis Tools

We will need to acquire specialized analysis tools to perform the tests and make the reports described in this document. Some exist now, some can be purchased off the shelf, and some tools will need to be built. Section 6 describes some of those tools and how we may obtain them.

1.2. Parent Documents

The parent documents for MODIS L1B QA Plan are the Team Leader Working Agreement[*Salomonson*, 1994], the MCST Management Plan[*Barbieri and Guenther*, 1995], and EOS directives[*King and Sellers*, 1994].

1.3. Related Documents

Related documents include the MODIS Level 1B Algorithm Theoretical Basis Document 1995[*Jones et al.*, 1995], the MODIS L1B Validation Plan[*Barbieri*, 1996], and the MODIS Calibration Plan[*Zukowski et al.*, 1995].

2. L1B Science QA Flags and Fill Values

2.1. QA Flags

The MODIS L1B quality assurance flags are applied to the current scan line based on the telemetry used to calibrate the current scan line. These flags are applied to each MODIS channel every scan line. There are five top level flags (see Table 1) intended for use by the MODIS Science Team which are a summary of the 45 detailed diagnostic flags (see Table 5). All 50 summary and diagnostic flags will be stored in the L1B calibrated granule.

Logically each flag represents a single bit. You could therefore consider a logical structure associated with each scan line of an array of binary QA flags with dimensions of 490 MODIS channels by 50 QA flags. Computer storage requirements are unlikely to allow 50 bit fields to be exactly represented. The implementation of the computer storage and access mechanisms for the flags will be specified in the MODIS Level 1B Data Product Format[*Hopkins et al.*, 1995] for version 2 of the production software. That version of the report is planned by December 1996.

Table 1 Summary QA Flags

#	Flag Name	Description	Impact
1.	Non-Routine Instrument Operations	Indicates that a non-routine event is occurring which may affect calibration. These events are: SRCA turned on; SD door open; OBC blackbody heater on; OBC blackbody at an elevated temperature (5K above cavity); and Moon visible to SV based on orbital geometry.	Calibration product is usable, but may exceed budget and specification.
2.	Marginal Calibration Data	Indicates some missing calibrator data and/or relevant thermistor data and could exceed the calibration budget and exceed the MODIS specification.	Usable calibration product which could exceed budget and could exceed the allowable specification.
3.	Bad Calibration Data	Indicates missing calibrator data and/or relevant thermistor data to either provide no calibration product or a product which exceeds the calibration budget and specification.	No usable calibration product.

4.	Non-nadir Pointing	Indicates either a sector shift or a spacecraft maneuver.	Only usable for instrument characterization and calibration diagnostics.
5.	A & E Phase	Indicates that the spacecraft is in the A & E stage of the mission.	Calibration will not meet specifications because on-orbit characterization values will be determined based on an analysis of the data from this phase. All uncertainty estimates are set to 100% of their respective radiance or reflectance products.

2.2. Fill Data

Fill data are frame (sometimes known as pixel) specific indicators that a radiance, reflectance, or uncertainty cannot be calculated. The expected frame value is replaced with a bit pattern that indicates the problem that precluded the radiance, reflectance, or uncertainty calculation. Level 2 processing software must check for these fill values in each frame even if no QA flags have been set for the corresponding scan line. These fill values may occur in any of the data sectors, SD, SRCA, BB, SV, and EV. The same fill values may be used when L1A engineering count data can not be converted into engineering units during MODIS L1B processing. **Special care should be used to avoid averages, smoothing, or statistical calculations that would use these fill data as valid radiances, reflectances, or uncertainties.**[1]

Table 2 Fill Data

Number	**Fill Data Name**	**Fill Value (Decimal)**
1.	Invalid L1A data	65535 (Example)
2.	Dead detector	65534 (Example)
3.	L1B calibration failure	65533 (Example)
4.	Saturated detector	65532(Example)
5.	Radiance too low to represent	65531 (Example)
6.	Reserved for future use	65480-65530 (Example)

[1] This statement would not be in boldface if the authors had not made this mistake themselves.

3. L1B Production QA Metadata

Each MODIS L1B granule will incorporate numeric summary information derived from tests made during the processing of that granule.

Table 3 QA Metadata

#	Name	Descriptions
1.	Total EV observations (B)	Total number of Earth View frames in granule
2.	Valid EV observations (B)	Number of valid Earth View frames in granule. Excluding Missing, Saturated, or Other observations.
3.	Missing EV observations (B)	Number of missing Earth View frames in granule
4.	Saturated EV observations (B)	Number of saturated Earth View frames in granule
5.	Other EV observations (B)	Number of other invalid Earth View frames in granule. Reserved for future use.
6.	Static Radiometric Uncertainties (B)	Static uncertainty estimates by band. These uncertainties are determined prelaunch and do not change in orbit. Predominately uncertainties in traceability to national standards of radiance.
7.	Dead Detectors (B,D)	List of the FPA detectors that can not be calibrated accurately
8.	Noisy Detectors (B,D)	List of the FPA detectors known to display noise beyond the specification NEdL. Depending on the characteristics of the noise, the data product uncertainty estimates at a given time may be too low.
9.	Post processing indicates bad data(B,D)	These values are updated after processing if post-production analysis indicates that all the values from one or more detectors should not be used for science evaluation. A TRUE value indicates bad data. These values are always set to FALSE during normal processing.

(B) - Indexed by each MODIS band.

(B,D) - indexed by MODIS band and detector within the band.

4. Engineering Data

4.1. L1B by granule

Within each granule calculate the:

N, Number of observations
Mean, Mean value of the observations,
Sigma, Standard deviation of the observations,
Min, Minimum value recorded in the granule,
Max, Maximum value recorded in the granule ,
for each of the engineering data variables.

These results will be transferred to the TLCF at the end of each L1B within granule process. In the TLCF the results will be stored in a convenient fashion for time series analysis. The intent is to build a complete record of these engineering parameter statistics over the life of each MODIS instrument. We expect these records to be valuable for studies of the time dependent state of the MODIS instrument, and for correlative studies with calibration parameters.

The expected data volume stored in the TLCF at the end of instrument life is estimated to be <8GB.

4.2. Within the TLCF

Within the TLCF several analyses will use this engineering data. One of the first activities during A&E will be forming histograms of raw DNs thorough each of the A/D converters used for engineering data. We will be looking for DN values or patterns of values that never occur. Broken wires or internal D/A flaws can create such patterns.
We will need time series analysis tools in the TLCF plot the data extracted from the L1B granules and compare the values to established high and low limit values. Trending and extrapolation of trends will also be needed with polynomial and harmonic fitting functions.
We will also need similar tools that work on L1A and L1B granules for more detailed time series.

5. Trending and Consistency Analysis

It is critical to accurately identify the operations of data extraction and statistical analysis that will occur in the L1B code in a timely fashion because of the tight schedule leading to Version 2 code delivery and subsequent infrequent opportunities for change. The information in Table 4 provides the priorities for the activities listed in the MODIS L1B QA Plan and where processing is performed.

Priority 1 means that changes are required in the L1B Within Granule CSCI. Full details must be specified by October 31 1996 for delivery to SDST in L1B version 2.0 by February 1997.

Priority 2 means that this test will take place in the TLCF and is required at launch. The algorithm and needed software should be coded, tested, and under MCST configuration control by launch minus one year, June 1997.

Priority 3 means the analysis will take place in the TLCF and will be completed as resources permit.

An X in a column means that some of the unique processing for the named QA test will take place in this processing system.

The goal is to identify additional resources beyond those needed if the QA test did not occur. As an example a QA test that orders an L1B granule from the GSFC DAAC and performs a linear correlation between two thermistors on the TLCF would have an X only in the TLCF column even though substantial effort took place in the Within Granule processing system to create and store the granule in the DAAC originally. A similar test that required code in the Within Granule processing stream to extract the readings from the two thermistors, record the readings in a file, and transmit the file to the TLCF at the end of the processing would have X's in both the Within Granule and TLCF columns.

Table 4 Priorities and Processing Locations

QA Test	Within Granule	Cross Granule	TLCF	Priority
QA Flags and fill data	X	X		1
QA metadata	X	X		1
Engineering trend data	X		X	1
1. SRCA to SD radiometric comparison			X	3
2. Band to band temporal consistency			X	3
3. Lunar to SD radiometric			X	3
4. SD measured irradiance to published values			X	3
5. Intra-orbit variations			X	3
6. Trapped Radiation Effects in the SV and SDSM	X		X	1
7. SV and BB in Reflective Bands			X	3
8. SD effects			X	3
9. SRCA effects			X	3
10. Electronic Calibration	X		X	1
11. Ice accumulation	X		X	1
12. Use of Heated Blackbody to Monitor Thermal Calibration			X	3

Nonlinearity				
13. Trends of spectral measurements			X	3
14. Trends of spatial measurements			X	3
15. SRCA lamp resistance and models			X	3
16. Scan Overlap Within-Band Calibration Monitoring				3
17. IR Short Scale Noise Time Series				3
18. IR Medium Scale Time Series			X	3
19. Mirror Side Evaluation of Darkness			X	3
20. Correlations of EV and SV Signals			X	3
21. Long-Period SV, SD, and SDSM Harmonics			X	3
22. Change Point Detection in Responsivity Trend Line			X	3
23. Multiple-Orbit Temperature Telemetry Power Spectra			X	3
24. Analog Temperature Telemetry Change Point Detection			X	3
25. Trends of SDSM SNR			X	3
26. SDSM Stray Light			X	3
27. SDSM Channel Linearity			X	3
28. Reflective Band Linearity from SD Measurements			X	3
29. Trends of MODIS SNR From SRCA and SD Measurements			X	3
30. Co-regestration of bands based on spatial correlations in scenes of high ground contrast			X	3
31. Radiance Histograms	X		X	1
32. EV Coherent Noise and Banding	X		X	1

Any trending or consistency analysis listed in section 5 or any that may be added later should answer the following questions:

1. What is the name for the analysis?
2. What MODIS data is being analyzed?
3. What characteristic of MODIS or assumption used in an algorithm is verified or studied in the analysis?
4. How will the analysis be performed?

5. What is the schedule for the analysis?
6. In what format or forum will the results of the analysis be reported?
7. What special tools will be needed to complete the analysis?

A section may have several answers. An analysis could lead to an article in a peer reviewed journal, a presentation at a MODIS Science Team Meeting, a data set generated as an HDF file and archived at the GSFC DAAC, and a request to the MODIS Team Leader for a change in the calibration algorithm.

It is worth noting that these analysis are intended to verify the assumptions that have been made in the calibration process of MODIS. In general the expected results we obtain will only be of interest to those most interested in calibration. This leads us to report most of our results to the MODIS calibration review committee. Failures of the calibration process discovered during these analysis will be reported by MCST to the MODIS Team Leader through the existing MODIS Technical Team Meeting structure or other structures as defined by the MODIS Team Leader.

5.1. SRCA to SD radiometric comparison

5.1.1. MODIS data analyzed

The data analyzed includes the MODIS DN* from both the SRCA radiometric mode and the SD/SDSM radiometric calibration.

5.1.2. Assumption

The MODIS/SRCA system will transfer the radiometric calibration from prelaunch to orbit to the SD/SDSM. After A&E the SD/SDSM will maintain radiometric calibration. MODIS radiometric responsivities from the SRCA, SD/SDSM, and other sources will be trended. We expect smoothly varying responsivities from the SD/SDSM measurements and that the SRCA results will remain consistent with the SD/SDSM.

5.1.3. Analysis

The SRCA/MODIS system will transfer radiometric calibration onto orbit during the A&E phase. After A&E the SRCA radiometric performance will decrease because of possible degradation of: lamp filament emissivity, reflectance of the SRCA SIS wall material, transmission/reflectance of the SRCA system components, and reference SiPD responsivity.

The MODIS radiometric responsivities are estimated from various calibrator data including: prelaunch MODIS, the SRCA (for constant radiance and constant current), the SD/SDSM illumination and others. These estimated responsivities will be tracked with a time series in orbit and trend curves will be produced and intercompared.

Consistency of the MODIS signal under SRCA illumination and/or consistency of SRCA reference SiPD signal in spectral mode during two consecutive SRCA calibrations provides a self-check of stability of the SRCA.

5.1.4. Schedule

The SRCA data to perform this analysis will be collected every time the SRCA is in full radiometric mode. The time series analysis of responsivities will be done at least every six months throughout the MODIS mission.

5.1.5. Presentation and results

The reference SiPD data in spectral mode will be used to monitor the change of SIS output and transfer the radiometric calibration to orbit during the A&E phase. Thus the MODIS DN data in radiometric mode must be saved with the reference SiPD data in spectral mode in the L1B product. All the SRCA housekeeping data will be saved in separate files for future reference. It is also important during the A&E phase to monitor the SRCA stability and normal operations and to evaluate the capability of the SRCA radiometric transfer.

The MODIS DN* values under the SRCA illumination will be saved in designated files for consistency tests.

Current responsivities will be available at each meeting of the MODIS calibration review committee.

5.1.6. Special tools

The time series analysis tools will be needed.

5.2. Band to band temporal consistency

5.2.1. MODIS Data Analyzed

The time series of band averaged solar reflective band responsivities, SD BRDF determinations, and SD radiances determined by SD/SDSM measurements.

5.2.2. Assumptions Tested

MODIS calibration in the solar reflective bands is performed on single detectors. Many of the level two algorithms depend on band ratios. If the calibration strategy is correct then the band to band ratio for any two bands of the product of the SD radiance and the SD BRDF in the observation geometry should remain constant.

5.2.3. Analysis

There are 231 unique band ratios among the solar reflective bands (bands 13 and 14 have two gain settings each). For each of these ratios the radiance-BRDF product will be calculated. We will look for significant variations from constancy in the time series of each ratio.

5.2.4. Schedule

The data will be collected each time the SD / SDSM analysis is completed. The trends and significance analysis will be performed at least twice a year.

5.2.5. Presentation of Results

Results will be presented to the MODIS calibration review committee.

5.2.6. Special Tools

IDL

5.3. Lunar to SD radiometric

Plans for lunar analysis are under development.

5.4. SD-Measured Solar Irradiance Compared to Published Values

5.4.1. MODIS Data Analyzed

SD effective DN during a solar calibration period.

5.4.2. Assumptions Tested

During A&E a sequence of solar reflective band measurements will be made using the SD which effectively provide estimates of the within-band solar spectral irradiance. The largest components of the uncertainty in the MODIS solar irradiance measurement are the prelaunch radiance responsivities, and the SD BRDF, whose prelaunch biases are expected to be 5% and 2%, respectively.

5.4.3. Analysis

During A&E, after the instrument is considered stable, SD measurements over several calibration periods are made. The calculated SD radiances, based on the accepted A&E radiance responsivities, are regressed against the theoretical SD radiances which depend on solar geometry, and SD BRDF. The slope of the regression line is the within-band solar irradiance. Comparisons of the MODIS solar irradiances will be performed relative to accepted measures [*Neckel and Labs*, 1984] with appropriate corrections needed to bring both sets of measurements to the same ‘scale’. Such corrections may involve defining the MODIS pass-band, compensation for the gold-point blackbody standard relative to the SIS(100)-based MODIS calibration standard, and other effects.

5.4.4. Schedule

Once in A&E.

5.4.5. Presentation of Results

Peer reviewed journal article.

5.4.6. Special Tools

IDL

5.5. Intra-orbit variations

5.5.1. MODIS data analyzed

The data include: Radiance in radiometric mode, center wavelength in spectral mode, and detector position shift along-scan and band centroid position shift along-track in spatial mode for solar reflective bands (1-19 and 26). These parameters are functions of MODIS DN*s, SiPD and other engineering measurements.

5.5.2. Assumption

If the SRCA calibration is stable intra-orbit, we can attribute the measurement variations to the MODIS performance change within orbit.

5.5.3. Analysis

During the A&E phase, the three SRCA modes: radiometric, spectral and spatial calibrations will be performed periodically. In orbit data collection requires 17, 37, and 75 minutes for complete radiometric, spatial, and spectral modes, respectively. The orbital period is about 100 minutes. Data collection for each of the three modes will be initiated at three different orbit positions to assess intra orbit variations. A 10W and a 1W lamp will each be on in radiometric mode for a full orbit.

Multi-orbit information could support the possible corrections of MODIS calibration, as a function of orbital position and/or temperature, in the three modes if the resulting data present a persuasive trend which leads to correction algorithms

5.5.4. Schedule

SBRS will measure MODIS DNs when the SRCA 1-10W and 1-1W lamps (in radiometric mode) are on over a temperature range at TV. This will provide the information about the SRCA output stability as a function of environmental temperature variation. We suggest that SBRS also run the spectral and spatial calibrations at different temperature levels during TV testing in order to understand the temperature effect on the SRCA spectral and spatial calibrations.

In orbit this test will be run mainly during the A&E phase. Since this is the only approach to examine the radiometric, spectral, and spatial performances of MODIS intra-orbit, the L1B process should be able to extract the data and save it in a separate file. It needs to be accessible any time during A&E phase.

5.5.5. Presentation and results

These results will be regularly reported and presented to the MODIS calibration review committee.

5.5.6. Special tools

The time series analysis tools will be needed.

5.6. Trapped Radiation Effects in the SV and SDSM

5.6.1. MODIS Data Analyzed

Full 16 day MODIS orbital repeat cycle of SV DNs before conversion to DN*, and band averaged with no outlier rejection. Data are averaged over each granule and included in the QA data file sent to the TLCF at the end of each L1B production run. Latitude, longitude, and time of the subsatellite point at the beginning of each granule. Also needed are the SDSM DCR DNs for each SDSM band, with no averaging or outlier rejection.

5.6.2. Assumptions Tested

The SV is used as the zero radiance source for the MODIS bands, and the SDSM measurements made during a solar calibration period provide the estimate of the SD degradation factor. The SBRS design of all the MODIS detectors required a nominal level of isolation from the trapped radiation environments encountered in a typical orbit at 705 km. However there is a potential for charged particles to strike the SDSM and MODIS detectors producing electron-hole pairs which will contribute to anomalous output at the respective A/Ds. Thus the DNs from the SV and SDSM DCR used for zero subtraction may be biased.

5.6.3. Analysis

The mean SV DN values will be binned on a 1 degree by 1 degree latitude-longitude grid based on the subsatellite position. A map will be constructed. Significant variations (>1 NEdL) over the map will indicate need for further analysis of responsivity variations.

The SDSM must be powered-up with fold-mirror parked at the DCR position, and DN measurements recorded at 1.477s sampling intervals over several contiguous. The set of orbits selected must be centered around the longitude of peak SAA activity (as determined from external data sets). The measurements are spatially segregated by latitude and longitude into four sets of time series as characterized by occurring within the SAA, within the two polar regions, and outside the previous three regions. The four sets of measurements are compared with a standard two-sample mean T-tests and two-sample variance F-tests in order to detect the influence of particle effects on the SDSM DN. If the tests indicate significant effects, the SDSM DNs associated with particle events provide prior information to the SDSM outlier-rejection algorithm.

5.6.4. Schedule

For SV analysis, annually. For SDSM analysis, once during A&E, once during a period of time when solar flare particles are known to have been trapped in the polar horns, and annually during SV sampling.

5.6.5. Presentation of Results

MCST internal memorandum.

5.6.6. Special Tools

PGS Toolkit, IMSL, IDL.

5.7. SV and BB in Reflective Bands

5.7.1. MODIS Data Analyzed

The DNs of solar reflective bands in samples of SV and BB data sectors. These will include granules where the moon is in the SV and others where it is not. Both spacecraft day and night data will be needed.

5.7.2. Assumptions Tested

The BB data sector may be useful as a replacement for the SV for some MODIS solar reflective bands when the moon is visible through the SV or if the SV data is unavailable for any other reason.

5.7.3. Analysis

Mean and standard deviation values for each of the MODIS solar reflective bands will be calculated in both the SV and BB data sectors. The significance of any differences will be calculated. An error analysis comparing the use of the BB as a zero radiance source in the solar reflective bands compared to holding the zero radiance at the last measured value through a lunar mode period will be performed.

5.7.4. Schedule

This is considered a low priority analysis. It is expected to be performed once during the MODIS AM-1 mission.

5.7.5. Presentation of Results

This results will be in the form of an MCST internal technical memo.

5.7.6. Special Tools

Tools to extract BB and SV counts from L1A granules and perform simple statistics. We will also need to modify and compare the uncertainty model for the solar reflective bands.

5.8. SD effects

5.8.1. MODIS Data Analyzed

BB data for the thermal bands. SV data for all MODIS bands. Science day mode EV data for all bands. This data must include some data preceding the SD illumination and some during the SD illumination. Engineering data indicating the BB temperature. SD radiances for all MODIS bands.

5.8.2. Assumptions Tested

We assume that illuminating the SD does not significantly affect the radiometric responsivity of any of the MODIS bands in the EV data sector or SV data sectors. We also assume that the SD does not significantly affect the BB temperature and the thermal band radiometric algorithms.

5.8.3. Analysis

Compare average levels of DNs in the SV and EV data segments before and after the SD is fully illuminated. The visible channels in the SD data segment should identify the illumination unambiguously. The measured changes and their significance will be calculated. The measured changes should be propagated through the MODIS uncertainty analysis to determine the effect on uncertainty products and specifications.

A similar analysis will look for changes in the temperature of the BB and propagate them through the thermal band uncertainly model.

5.8.4. Schedule

Aging effects may change the scatter characteristics of MODIS over its lifetime. This analysis should be repeated annually.

5.8.5. Presentation of Results

The results of the analysis will be reported to the MODIS calibration review committee.

5.8.6. Special Tools

Tools to extract data from L1B granules and perform simple statistics. MODIS uncertainty models.

5.9. SRCA effects

5.9.1. MODIS Data Analyzed

SV, BB, and day science mode EV data. This should be taken with no SRCA bulbs lit and with 3 10 watt bulbs illuminated in SRCA radiometric mode. Science day mode data while above Earth night is particularly useful.

5.9.2. Assumptions Tested

Turning on the bulbs of the SRCA should not significantly change the radiometric response of any MODIS bands in the SV or EV data sectors. It should not change the radiometric response of the thermal bands in the BB data sector.

5.9.3. Analysis

Compare average levels of DNs in the SV and EV data segments before and after the SRCA is fully illuminated. The visible channels in the SRCA data segment should identify the illumination unambiguously. The measured changes and their significance will be calculated. The measured changes should be propagated through the MODIS uncertainty analysis to determine the effect on uncertainty products and specifications.

A similar analysis will look for changes in the response of the thermal bands to the BB and propagate them through the thermal band uncertainly model.

5.9.4. Schedule

Aging effects may change the scatter characteristics of MODIS over its lifetime. This analysis should be repeated annually.

5.9.5. Presentation of Results

The results of the analysis will be reported to the MODIS calibration review committee.

5.9.6. Special Tools

Tools to extract data from L1B granules and perform simple statistics. MODIS uncertainty models.

5.10. Electronic Calibration

5.10.1. MODIS Data Analyzed

Calculated radiances from the SRCA data sector for reflective solar and thermal PV bands. Calculated radiances from the SV sector for the thermal PC bands. This data is collected for all consecutive scans while electronic calibration is on.

5.10.2. Assumptions Tested

The MODIS analog electronics is assumed to be linear. The correlation of scan number to response during electronic calibration should show that linearity.

5.10.3. Analysis

Date will be taken from the SRCA sector for reflective solar and thermal PV bands. Data will be taken from the SV sector for the thermal PC bands. A linear correlation coefficient, r, will be calculated for each detector between scan time and the response data. The value of r is expected to be >0.9.

5.10.4. Schedule

Electronic calibration is planned once per month during normal operations. The data will be collected and analyzed after each electronic calibration.

5.10.5. Presentation of Results

The results will be in a series of MCST internal memos.

5.10.6. Special Tools

Tools to extract data from L1B granules and perform simple statistics.

5.11. Ice accumulation

Water ice may accumulated in the MODIS optics. It may be possible to detect this accumulation using ratios of thermal band responsivities. Ratios of bands sensitive to ice absorption to those insensitive to water ice are the prospective diagnostics. The details of this analysis are still under development. It will require thermal band responsivities to be available in the TLCF. This would require some modification of the L1B version 1.0 code.

5.12. Use of Heated Blackbody to Monitor Thermal Calibration Nonlinearity

By heating the OBC blackbody, it may be possible to check if the nonlinearity of the system response has changed since protoflight and A & E measurements. Nonlinearity measurements with the OBC blackbody will have systematic differences from the measurement with the BCS ground calibrator. However, the purpose of this trend is to determine whether the nonlinearity is changing and not to correct for this change.

5.12.1. MODIS Data Analyzed

All telemetry used by the thermal calibration algorithm will be needed for this analysis. This will include all scans taken from about 5 minutes before the OBC blackbody heaters are turned on to the point where the OBC blackbody has cooled down to a stabilized ambient temperature. This will include PFM, A & E, and regular mission data.

5.12.2. Assumptions Tested

The current assumption is that the nonlinear response of the system will not change during the mission and that the system gain will only change slowly in time (no noticeable change over a period less than one hour).

5.12.3. Analysis

By making the assumption that the system gain doesn't change during the OBC blackbody heated mode, we can determine a nonlinear coefficient such that the linear least squares fit to the gain term (m) has a zero slope for the full set of heated mode data. The constant gain assumption can be validated by either heating the OBC blackbody two or three consecutive times within a short time period when the system gain should not change, or comparing heat up data with cool down data.

5.12.4. Schedule

During PFM testing we would like to use the heated mode two times done sequentially to validate the constant gain assumption but one time can suffice as long as we get both heat up and cool down data. During A & E we should use the heated mode at least three times with two times done sequentially to validate the constant gain assumption and the other time occurring several months later (or earlier) to validate constant nonlinearity assumption. After A & E the heated mode is currently scheduled yearly (TBR).

5.12.5. Presentation of Results

Analysis of the stability of the system nonlinearity will appear in presentations to the Calibration Review Committee and likely in published papers. The results may be used to affect the calibration uncertainties, especially for cloud and fire bands.

5.12.6. Special Tools

L1B code will be needed, or some version of it, to analyze the effect of differing nonlinearity values.

5.13. Trends of spectral measurements

5.13.1. MODIS data analyzed

MODIS center wavelength and shift measured by the SRCA in time series.

5.13.2. Assumption

It is assumed that the ratio of the spectral responses of the calibration SiPD and the reference SiPD is invariant with time.

MODIS out-of-band response remains at its prelaunch level.

5.13.3. Analysis

Up to the A&E phase, MODIS will suffer environmental changes from ground to orbit. The variation of the MODIS center wavelength will be tracked to understand its change with environment.

The center wavelength for each MODIS band will be trended over the MODIS mission. Any abnormal variation in spectral band shifts will provide an early warning to check the stability of the spectral calibration operation or to suggest a check of the band performance. The stability of the SRCA spectral self-calibration will also be examined. It includes the repeatability of the measured monochromator parameters, β and $\theta_{off,}$ and the stability of the operational environment.

5.13.4. Schedule

The analysis should be performed in detail during the A&E phase because MODIS and the SRCA start operating from a transient to stable environment as MODIS goes from prelaunch to orbit. During A&E the SRCA spectral calibration will be operated much more frequently than in the subsequent operational phase. The spectral calibration results will be analyzed for thermal effects, orbital effects, and changes with time. The reference SiPD signal in spectral mode will also compensate for the effects due to the possible variation in the SRCA SIS spectral output or in the structural stiffness of the SRCA system. While in operation phase, the attention will be primarily concentrated on the timing effect.

5.13.5. Presentation and results

L1B product should include the band center wavelength, center wavelength shift. Additional information will be provided but not as L1B product including cut-in and cut-out wavelengths, band width, and the two monochromator parameters, β and θ_{off}. All this information must be saved in separate files for trending analysis and future reference.

This information will be regularly reported and presented to the MODIS calibration review committee.

5.13.6. Special tools

The time series analysis tools will be needed.

5.14. Trends of spatial measurements

5.14.1. MODIS data analyzed

MODIS detector position shift along-scan and the band centroid position shift along-track in time series.

5.14.2. Assumption

The FPA shift (translation and rotation) is the main mechanism of the spatial position variation on-orbit because the detector relative positions within each FPA remain invariant.

5.14.3. Analysis

The relative co-registration will be tracked over the MODIS mission. This information about the detector positions and shifts will be interpreted as along-scan and along-track shifts plus rotation and magnification of each of the four FPAs. The positions of dead / saturated bands will be determined using position interpolation from its vicinity bands / channels. The trends of spatial measurements will further provide information about the four FPA position stability over time in orbit.

The FPA position shifts over time will be related to environmental variations. Within each FPA detector position shifts along-scan and band centroid position shifts along-track should be consistent with rigid body movement; this will be the basis for testing consistency of detector shifts.

5.14.4. Schedule

The analysis should be performed in detail during A&E phase because MODIS and the SRCA will have just gone through the launch phase with changes in the environment. During A&E the SRCA spatial calibration will be performed much more frequently than during the operational phase. The spatial calibration results will be analyzed for thermal effects, orbital effects, and trended. While in the operational phase, the attention will be primarily concentrated on trending.

5.14.5. Presentation and results

The L1B product should include detector position and shift along-scan, band centroid position and shift along-track in time series. Supplemental information includes the FPA shifts in both along-scan and along-track, FPA rotation, and magnification in time series. This information must be saved in separate files for trend analysis and future reference.

These results will be regularly reported and presented to the MODIS calibration review committee.

5.14.6. Special tools

The time series analysis tools will be needed.

5.15. SRCA lamp resistance and models

5.15.1. MODIS data analyzed

The SRCA lamp filament emission efficiency, lamp current, and voltage recorded as engineering parameters of MODIS.

5.15.2. Assumption

5.15.3. Analysis

The degradation information of the SRCA lamp filament emission efficiency, lamp current, and voltage described and the use of lamp aging models will be used to predict when the lamps need to be changed or are about to fail and the confidence of the use of the SRCA. The lamp aging models are expected to follow those of E.H. Johnson in [*Johnson*, 1995] and [*Johnson*, 1993].

5.15.4. Schedule

Start trending over time upon orbit.

5.15.5. Presentation and results

These information is for monitoring the SRCA operation only. The expected result is an internal MCST report.

5.15.6. Special tools

The time series analysis tools will be needed.

5.16. Scan Overlap Within-Band Calibration Monitoring

5.16.1. MODIS Data Analyzed

L1B-derived radiances and reflectances from spatially-overlapped samples from successive pairs of EV scans. Also referred-to as bowtie sampling. The percentage of spatial overlap should be greater than 90%. The geolocation data for each frame in the scan are needed.

5.16.2. Assumptions Tested

After a solar calibration period the estimates of the MODIS responsivities for every channel within a band are internally consistent when measuring the flat-field radiance of the SD. As time progresses toward the next solar calibration period, the responsivities may change, and the rate of divergence in the radiances or reflectances, will be estimated by the bowtie sampling.

5.16.3. Analysis

The bowtie radiance or reflectance samples are assumed to be a random sample from a bivariate normal distribution. The distribution's correlation coefficient, ρ, is a measure of the closeness of the radiances / reflectances in the bowtie. Standard confidence intervals for ρ will be calculated, and values significantly different from unity indicate that relative drift occurred between the channel-pairs sampled. Responsivity differences will be estimated from sample sizes on the order of one orbit. The relative difference of the sampled-derived value of ρ from unity is a measure of the departure from a flat-field.

5.16.4. Schedule

Performed in TLCF. Initially performed as a proof-of-concept study, and with further development as a potential component of L1B. L1B output data file containing the 90% overlap frames for each data period are needed. If included as an operational procedure, an operator must visually inspect the scatter plots for selected detector pairs on a monthly basis.

5.16.5. Presentation of Results

Sample correlation coefficients plotted as time series throughout the mission provide information about the relative rates of channel degradation, and the level at which the SD calibration process produces consistency among the L1B-calculated radiances and reflectances.

5.16.6. Special Tools

PGS Toolkit, IMSL, IDL.

5.17. IR Short Scale Noise Time Series

5.17.1. MODIS Data Analyzed

Time series of BB and SV data for all thermal channels over 100 scans.

5.17.2. Assumptions Tested

The uncertainty model of the PC thermal bands includes an assumption that the noise in these bands is a combination of gaussian and 1/f noise terms. This model is characterized by two parameters. They are N_0 the (Noise Voltage)/(HZ)$^{1/2}$ in the high frequency limit and f_c the corner frequency where white noise equals 1/F noise. The assumption in the PV thermal channels is that 1/F noise is negligible.

5.17.3. Analysis

The N_0 and f_c parameters will be estimated for each thermal channel using the BB and SV data at time scales from one frame to 100 scans. The data corresponding to the phase space between time scales of 50 frames and 1 scan does not exist and makes an FFT analysis difficult therefore a maximum likelihood analysis will be used.

5.17.4. Schedule

The analysis should be performed annually during the mission.

5.17.5. Presentation of Results

A set of analysis over several years is expected to be published in a journal article. Interim reports will be made to the Calibration review committee.

5.17.6. Special Tools

What special tools will need to be used to complete the analysis?

5.18. IR Medium Scale Time Series

5.18.1. MODIS Data Analyzed

Statistics on responsivity and offset values (m, Lo, Fs) for each of the thermal channels will be collected in each L1B granule and sent to the TLCF for analysis at the end of each L1B processing run. Statistics extracted include minimum, maximum, number of observations, mean and standard deviation.

5.18.2. Assumptions Tested

These statistics will be available for trending and for time series analysis on a scale of years. They will also be available for correlative studies with observed anomalies or patterns in calibration performance.

5.18.3. Analysis
Time series plots are the major analysis until anomalies are detected.

5.18.4. Schedule
The time series on scales of weeks will be plotted and manually scanned at least twice a year.

5.18.5. Presentation of Results
The results will be stored in MCST during each mission. Annual compilations of the data will be sent to the GSFC DAAC as a special data product.

5.18.6. Special Tools
Time series analysis tools. Formats and tools for this time series and the engineering data should be similar.

5.19. Mirror Side Evaluation of Zero Radiance Targets
The need for this test is based on non-null results of a similar test in EM data.

5.19.1. MODIS Data Analyzed
Solar reflective band observations of the SV and BB data sectors with information on which mirror side was used for each scan.

5.19.2. Assumptions Tested
This tests the assumptions that the detector responsivity is unchanged on a scan time scale, that there is negligible scattered light in the SV for these bands, and that other contaminating noise sources are absent from the SV data. The BB is another dark target that should show the same results.

5.19.3. Analysis
Determine mean and standard error values of the SV and BB separately for each mirror side in the reflected solar channels. The difference in the mean measures the violation of the assumptions. The standard error determines the significance of the violation. Similar tests for some bands during Engineering Model (EM) testing showed small (0.2 counts) but significant violations of these assumptions. It appears prudent to look for the effect in samples of flight data.

5.19.4. Schedule
A test that results in no significant violations of the assumptions will only need to be run infrequently. Every two years is planned.

5.19.5. Presentation of Results
The results will be described in an MCST internal memo.

5.19.6. Special Tools
Tools to extract L1B data and perform simple statistics.

5.20. Correlations of EV and SV Signals

5.20.1. MODIS Data Analyzed
One orbit of MODIS data.

5.20.2. Assumptions Tested
If the SV is not contaminated by stray light or other common mode noise then the band average SV signal in a scan line will be uncorrelated with the band average EV signal in the same scan line.

5.20.3. Analysis
The analysis will consist of taking an orbits worth of MODIS data and calculating band averages of the 15 center frames of the SV and EV for enough scans to make a good scatter plot. A suggested starting point is 200 scans selected randomly from the day science mode for solar reflective bands and from both day and night mode for the thermal bands.

Once the scans are selected create a scatter plot of band average SV value versus band average EV value. No correlation is expected. Visually distinct correlations should be investigated. The statistic that can be automatically calculated is the linear correlation coefficient of the two data sets. If a correlation is found that is significant at the 95% level then further investigation is warranted.

5.20.4. Schedule
Should be done annually.

5.20.5. Presentation of Results
Reported to the calibration review committee

5.20.6. Special Tools
Tools for linear correlation coefficient and scatter plots. Data extraction and averaging for significant amounts of MODIS L1B data.

5.21. Long-Period SV, SD, and SDSM Harmonics

5.21.1. MODIS data analyzed

SV buffer means and standard deviations, SDSM DCR (DC restore) DN, SDSM DN in Sun-view mode.

5.21.2. Assumptions to be tested

The SV serves as the offset correction for all MODIS bands, and was designed to be a stable source of zero radiance as long as the IFOV of the scan mirror is contained solely within the SV during normal operation (moon not in SV; no maneuvers; etc.). Stray light is not expected to contribute into the IFOV during SV sampling.

The SDSM DCR is the SDSM signal collected during the periods when the SDSM fold-mirror rotated to the internal housing. The fold-mirror aperture is contained within a light-proof rotating assembly to eliminate the possibility for stray light to enter the SDSM housing during DCR operations.

The SDSM Sun-view and SD-view signals are combined in L1B to estimate the SD degradation factor which is needed for the calculation of SD radiance. The SDSM samples the direct solar flux transmitted through a screen with transmittance 2%. Variation in the solar flux at the SDSM aperture during Sun-viewing is caused by the changing incident solar geometry in combination with the screen/aperture obliquity factor. This variation is compensated in L1B with A&E data, characterization and modeling of SDSM screen transmittance. The compensated average at-SDSM-aperture signal from Sun-view sampling exhibits a 3% annual variation due to the Sun-Earth distance change over the year superposed onto a gradual drift resulting from SDSM channel output degradation.

5.21.3. Analysis

The MODIS scan mirror BSDF causes scattering into the IFOV from the SV-surround during offset determination. The SV buffer means are used as input in a time series/regression analysis to detect cyclical components correlated with SD door openings, and the solar annual cycle. Such components may be traced to stray-light entering the IFOV from the SV-surround.

The SDSM fold-mirror aperture rotates in a nested assembly whose dimensions are such that there is a potential for stray light to enter the SDSM housing during DCR operations. The stray light leakage may posses a signature which depends on the solar geometry, which in turn depends on the epoch. Time series/regression analysis will be used to detect cyclical trends in the SDSM DCR signals.

The SDSM Sun-view means corrected for SDSM angular response will be subjected to a time series/regression analysis designed with solar annual Sun-Earth-distance, and long-term trend components. The estimated parameters of the time series characterize the long-term behavior of the SDSM, and analysis of the residuals will provide information on the efficacy of the SDSM angular response correction.

5.21.4. Schedule

Performed monthly as solar calibration data from the SD/SDSM become available. Data from current time series are appended to the corresponding historical time series, and each new data set reanalyzed.

5.21.5. Presentation of Results

The time series/regression analysis of the various signals described above results in a set of parameters which represent the correlation of the signal to the model components, i.e. door openings, solar cycle, etc. Parameter estimates will be trended as new data are collected, and significant results which warrant further analysis will be reported to the calibration review committee.

5.21.6. Special Tools

PGS Toolkit, IMSL library, IDL.

5.22. Change Point Detection in Responsivity Trend Line

5.22.1. MODIS Data Analyzed

MODIS solar reflective band responsivities.

5.22.2. Assumptions Tested

The solar reflective band responsivities are expected to change throughout the mission life. This change is expected to occur gradually as each channel's physical components age, however the overall degradation for a given channel may have localized 'discontinuities' in time which are caused by the competing factors in the degradation process.

5.22.3. Analysis

The MODIS responsivity estimates calculated in L1B for each solar reflective band channel are used in a time series/regression to calculate the responsivity prediction line, or the trend line. Sometimes a regression can be reasonably represented by two intersecting straight lines, one being appropriate when $t < T$ and the other when $t > T$, where t and T denote time, and T is called the changeover point. In such cases a two-phase linear model can be used to test the hypothesis that the changeover point is a given value. Its value can be specified in the test as either known or unknown. When a given changeover point is statistically significant, then the decision must be made to drop the earliest responsivity estimates from the responsivity trend function, in order that the linearity assumption of the channel degradation hold.

Such would be the case if the channel degradation were exponential instead of linear.

5.22.4. Schedule

Monthly as new solar calibration data are added to the cross-granule processing environment.

5.22.5. Presentation of Results

Significant changeover points are reported to the calibration review committee. The number of historical responsivities which are used in the responsivity prediction trend line must be adjusted in L1B tables.

5.22.6. Special Tools

PGS Toolkit, IMSL library, IDL.

5.23. Multiple-Orbit Temperature Telemetry Power Spectra

5.23.1. MODIS Data Analyzed

Passive analog temperature telemetry sampled at 1s.

5.23.2. Assumptions Tested

The sequencing in the MODIS EV and OBC sampling was designed to minimize potential electronic noise crosstalk between data-take periods and other events occurring within the system (the 'system' in this context can also be taken to mean the S/C platform). Indicators of potential crosstalk are data sets whose sampling frequencies are greater than the scan mirror rotation rate. The temperature telemetry are important inputs to the reflective and thermal algorithms, and as such need to be monitored for coherent noise to prevent biases which may contaminate the corresponding data products.

5.23.3. Analysis

Temperature analog telemetry data are normalized within a specified time window (Nyquist frequency TBD) in order to produce a statistically stationary (mean and variance constant) time series of measurements. Spectral and cross spectral estimates are calculated, and statistically significant spectral and co-spectral peaks reported.

5.23.4. Schedule

Selected orbits when known events, i.e. SD door/screen opening/closing, SDSM mirror motor activation. Once per month.

5.23.5. Presentation of Results
Frequencies corresponding to the significant power and cross spectral components reported to the calibration review committee. Significant components warrant special action in order to trace potential effects in the radiance / reflectance calibration and EV samples.

5.23.6. Special Tools
PGS Toolkit, IMSL library, IDL.

5.24. Analog Temperature Telemetry Change Point Detection

5.24.1. MODIS Data Analyzed
Passive analog temperature telemetry sampled at 1s.

5.24.2. Assumptions Tested
During A&E the temperature telemetry will provide a ‘training’ baseline for predicting the excursions of the various measured temperatures within the instrument. Discontinuities in a given thermistor’s record may fall within the nominal limits of operation, however the location (in time) of these discontinuities may be rare or randomly distributed, and thus, not detectable by the proposed spectral analysis described above. Potential discontinuities may be correlated in time with the calibration or EV sampling.

5.24.3. Analysis
An algorithm developed by Smid and Volf [*Smid and Volf*, 1996] forms the basis for detecting significant perturbations in each analog telemetry time series. The technique is based on spline interpolation and normalized Taylor coefficients, where the change point is detected as a singularity in the Taylor coefficients.

5.24.4. Schedule
Continuous process in TLCF. Selected temperature telemetry time series must be made available to the TLCF.

5.24.5. Presentation of Results
MCST memorandum. Significant times warrant special action to trace potential effects in the calibration and EV samples.

5.24.6. Special Tools
PGS Toolkit, IMSL library, IDL.

5.25. Trends of SDSM SNR

5.25.1. MODIS Data Analyzed
DN from SDSM DCR, Sun and SD sampling.

5.25.2. Assumptions Tested
The SDSM SNR directly contributes to the random error in the SD degradation factor. Accurate estimates of this quantity ensures accurate error bars for the output product.

5.25.3. Analysis
The SDSM SNR will be estimated from SDSM sampling using the cosine-corrected normalized SDSM DN for Sun-view and SD-view (both signals corrected for their respective screen transmittance variations). The mean values of both Sun and SD view are ratioed to their respective standard deviations to define the SDSM SNR. Results are compared to the MODIS specification.

5.25.4. Schedule
After each solar calibration period.

5.25.5. Presentation of Results
Time series of SNR for each SDSM channel will be appended with the current estimates. Results must feed back to L1B to update the random error tables.

5.25.6. Special Tools
PGS Toolkit, IMSL, IDL.

5.26. SDSM Stray Light

5.26.1. MODIS Data Analyzed
SDSM DN for DCR, SD-view, and Sun-view sampling.

5.26.2. Assumptions Tested
The SDSM fold mirror is enclosed in a nested assembly designed to minimize stray light from solar or SD sampling during DC restore (DCR) operations. Stray light in the DCR mode may be linked to the solar geometry on the SDSM screen, and/or the light in the calibration cavity during solar calibration periods.

5.26.3. Analysis

For each solar calibration period, the linear correlation coefficient (R) will be calculated for the two data sample pairs SDSM-DCR vs. SDSM-Sun, and SDSM-DCR vs. SDSM-SD, where the Sun-DCR and SD-DCR signals are normalized to account for cosine and screen transmittance effects. If no stray light contaminates the SDSM housing during DCR operations, then R will be small. Since the solar geometry varies throughout the year, R will become available for the various epochs, and inference on the solar geometry's effect on R will be made available.

5.26.4. Schedule

After each solar calibration period.

5.26.5. Presentation of Results

R appended to a graph containing the results from other solar calibration periods. Statistically significant values indicated and reported in an MCST memorandum.

5.26.6. Special Tools

IDL.

5.27. SDSM Channel Linearity

5.27.1. MODIS Data Analyzed

SDSM cross-granule data.

5.27.2. Assumptions Tested

The relative large change in the SDSM screen transmittance coupled with the changing solar incidence angle on the SDSM solar port produce significant variations in the SDSM detector flux. The sampling period between SD and Sun-view is 3-4.5 s, and during this period the Sun-view detector flux changes by a significant amount.

5.27.3. Analysis

SDSM Sun-view data.

5.27.4. Schedule

When cross-granule data are available.

5.27.5. Presentation of Results

Time series. Proposed correction to SDSM Sun-view.

5.27.6. Special Tools

IMSL, IDL.

5.28. Reflective Band Linearity from SD Measurements

5.28.1. MODIS Data Analyzed

Reflective band radiance responsivities derived from SD measurements of channels calibrated with screen-up and screen-down.

5.28.2. Assumptions Tested

If the reflective band channel response to radiant flux is linear over the dynamic range of the sensor, and no stray light contamination occurs on the SD and scan mirror, then the linear regression of detector DN vs. SD radiance will produce a radiance responsivity estimate independent of the overall level of SD radiance. The change in SD radiance is controlled by the solar geometry, and the SD screen (bands 1-7, 17-19, and 26 can be calibrated using both states of the screen). Normal operations during full SD illumination calibrate with screen up on one orbit, and screen down on the adjacent orbit, thus minimal channel degradation occurs in the time between both orbits. The two radiance responsivities derived from both screen states should be identical within sampling uncertainty. A non-normal calibration could be defined by extending the data-take period before and after the Sun is in full SD view. Such solar geometries cause the SD radiance to change from zero to maximum in a continuous predictable fashion if the geometry, and instrument metrology are known well. A non-linear response to radiant flux would indicate that a non-linearity correction should be performed.

5.28.3. Analysis

The standard F-test for parallelism of two straight lines is applied to each channel's SD data taken during screen-up and screen-down orbits. Significant differences are noted. Non-linearity can be determined from the SD light curve by relating SD radiance to DN as the Sun rises and sets in the solar port. Departure from linearity using this full dynamic range data set will be measured by regression with a second order polynomial.

5.28.4. Schedule

Performed on all cross-granule SD data.

5.28.5. Presentation of Results

Slope ratio time series derived from SD screen-up / down periods, and non-linearity determined from second order polynomial regressions are incremented for every channel after each cross-granule process, and the results presented to the calibration review committee. A consensus must be reached on whether to include the information in a L1B algorithm for linearity correction.

5.28.6. Special Tools

PGS Toolkit, IMSL, IDL.

5.29. Trends of MODIS SNR From SRCA and SD Measurements

5.29.1. MODIS Data Analyzed

Effective DN from SD, and SRCA sampling.

5.29.2. Assumptions Tested

The MODIS SNR corresponding to each band and channel of the solar reflective bands directly contributes to the random error in the calibration product. Accurate estimates of these quantities are needed as part of output product.

5.29.3. Analysis

The MODIS SNR will be estimated from SD sampling using the cosine-corrected SD effective DN corrected for screen transmittance effects, and adjusted to L_{typ} radiance levels. The mean signal ratioed to the standard deviation of the signal over the solar calibration period will define the SD-derived SNR. Similarly the SRCA DN corresponding to fixed SRCA radiances will be sampled by MODIS and ratioed to the corresponding standard deviations to define the SRCA-derived SNR. Both of the SNR estimates described above will be compared to the MODIS specification (GSFC).

5.29.4. Schedule

After each solar calibration period, and SRCA operation.

5.29.5. Presentation of Results

Time series of SNR for each channel will be appended with the current estimates. Results will feed back to L1B to update the solar reflective band random error tables.

5.29.6. Special Tools

PGS Toolkit, IMSL, IDL.

5.30. Co-regestration of bands based on spatial correlations in scenes of high ground contrast

5.30.1. MODIS Data Analyzed

SRCA estimates of spatial shifts and EV scenes of high radiometric contrast with geolocation information.

5.30.2. Assumptions Tested

The SRCA should measure relative spatial shifts of MODIS detectors in all bands. EV data for those bands that observe high contrast scenes should allow some band average spatial shifts to be observed. The EV data and SRCA measurements should be consistent. Some bands will generally see low contrast atmospheric features. These atmospheric bands may not be tested by this technique.

5.30.3. Analysis

High contrast scenes like shore lines will be manually chosen for each band where it is possible. A spatial correlation between pairs of bands will be used to estimate co-registration. A similar analysis of AVHRR data showing a shift of about 0.25 pixels was described in [*Allam*, 1986]. The results of the correlations will be compared to band averages of scan and track measurements from the SRCA. Significant differences will be noted.

5.30.4. Schedule

The analysis will be performed every year.

5.30.5. Presentation of Results

The results will be presented to the MODIS calibration review committee and to the SDST geolocation lead. The geolocation and OBC implications may result in journal articles.

5.30.6. Special Tools

Spatial correlation and visualization software.

5.31. Radiance Histograms

5.31.1. MODIS Data Analyzed

L1B-calculated radiance at the pixel level from each scan of all MODIS bands.

5.31.2. Assumptions Tested

On a given scan, two adjacent within-band detectors will, on average, receive the same distribution of scene radiance, especially over clear ocean, desert, or uniform cloud-cover. Thus, the frame-by-frame adjacent-detector radiance distribution functions will be the same. Departures from similarity are a measure of channel degradation, noisy, or dead detectors. In addition, radiance histograms serve as diagnostic tools in determining the gross morphology of the calibration process, examples being the pattern of negative radiances, A / D quantization, channel noise, saturation, etc.

5.31.3. Analysis

Histograms of the frame-by-frame radiance from adjacent within-band detectors are calculated from a granule. A Kolmogorov-type test will be used to determine whether the sample distribution functions are the same. Histograms of the frame-by-frame radiance difference calculated from adjacent within-band detectors are generated. The difference histograms combined with the individual channel histograms provide a measure of the within-band calibration consistency.

5.31.4. Schedule

Histograms of the channel radiance calculated by granule and placed in the L1B granule metadata. Recommended limits for radiance levels in the histograms are -3NeDL to L_{max} with 100 bins. Difference histograms based on selected granules from the DAAC and processed on the TLCF.

5.31.5. Presentation of Results

Anomalous histograms and corresponding causes are documented in MCST memoranda.

5.31.6. Special Tools

IMSL.

5.32. EV Coherent Noise and Banding

5.32.1. MODIS Data Analyzed

EV radiance for all bands at the granule level.

5.32.2. Assumptions Tested

The MODIS OBCs guarantee radiometric and reflective flat fielding in Earth-view sampling in the absence of other sources of noise. As time between successive recalibration (longest in the reflective bands) increases, the relative calibration between detectors will drift, and biases will appear in the retrieved data products. Also, the instrument manufacturer and platform integrator build systems which are, in theory, not to introduce spurious effects in the calibration, up to the level of the specification. Nevertheless, instruments in the MODIS heritage have been observed to produce artifacts such as coherent noise, and banding in the data products.

5.32.3. Analysis

Power spectral density estimation forms the basis for testing whether spurious cyclical noise appears in the EV data. The inputs are EV frames collected over relative large sample sizes, i.e. one granule or larger.

Coherent noise will be estimated by averaged power spectra of time series of EV pixel-level measurements from each detector over each scan line. It is expected that this form of noise is of relatively high frequency, and is most observable in the along-scan direction. Selected scenes with low geophysical variance, e.g. clear ocean, or desert, offer the best SNR in the calculated spectra. Significant spectral peaks will be calculated and analyzed with reference to other MODIS systems, i.e. electronics, motors, etc. Digital filters will be designed and tested for the removal of coherent noise.

Banding is evidenced by variation in the along-track direction from scan-to-scan. Time series will be constructed from the average of the within-band measurements from all detectors for a given frame number along-scan. Power spectra for the time series over all frames will be averaged, and significant spectral peaks recorded. Methods employed by Tilton et al., [*Tilton et al.*, 1984], Srinivasan and White [*Srinivasan et al.*, 1988] lay the groundwork for the analyses described above.

5.32.4. Schedule

DAAC requests for multiple granules are copied to the TLCF monthly and analyzed. An operator must view spectral plots for selected bands.

5.32.5. Presentation of Results

Significant spectral components discovered in EV scenes warrant investigation, and will be reported to the calibration review committee. Efficacy of the analysis presented above will determine if an unsupervised noise-removal algorithm is feasible as a component for L1B.

5.32.6. Special Tools

PGS Toolkit, IMSL, and IDL

6. Analysis Tools

This section is not complete in this draft. The intention is that this section will tabulate the special tools described in the analyses in sections 0 and 5. Other tools that will be necessary for analysis when we find anomalies in the data stream should be added. Tools providing the abilities in the list below are just possibilities. COTS tools like IDL with modest programming would fulfill many of these needs.

Correlations of Metrics
Correlations to Calibration Parameters
Temporal Plots of Multiple Parameters
Simple Fits to Multiple Parameters
Interpolation
Smoothing
Nonlinear Modeling
Residual Analysis
Descriptive Statistics
Temporal Statistics
Frequency Domain Analysis
Spatial statistics
Image Analysis

7. Appendices

7.1. References

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7.2. Detailed Diagnostic QA Flags

7.2.1. QA Flags for the L1B Within Granule Data Product

Most of the detailed diagnostic QA flags are a comparison of a value to a threshold value**.** The algorithms are the calibration algorithm most effected by a flag. The current valid categories are Thermal, MODIS, Other, SD / SDSM, SV, SW. These correspond to the Thermal, MODIS FPA detectors, Any Other category, The Solar Diffuser / Solar Diffuser Stability Monitor, Space View, and Software.

Table 5 QA Flags for the L1B Within Granule Data Product

#	Flag Name	Description	Threshold	Algorithm	Impact
1.	Negative Radiance Beyond Noise Level	Level 1B radiometric product some where in the scan line is significantly negative	3 * NEdL	MODIS	
2.	AEM Gain Change Locally	Applied electronics gains have been adjusted locally. Locally means it occurs within the 20 scans which precede the current scan (includes current scan) and it occurs within the 20 scans which follow the current scan.	NA	MODIS	
3.	Spacecraft Maneuver	Spacecraft maneuver is being performed.	NA	Other	
4.	SD Illuminated	If the solar diffuser is illuminated then stray light could affect the blackbody and space view radiance. If the SD door is open and the band average of any MODIS band exceeds a threshold in the SD data sector then this flag is set.	NEdL	SD / SDSM	The effect is currently not known and expected to be small. No contingency.
5.	SDS state change	SD screen in process of opening or closing during current scan. Motor step count not one of two values.	0 (closed) 1980 (open)	SD / SDSM	Possible effects on EV radiance or reflectance calibration

6.	SDD state change	SD door in process of opening or closing during current scan. Motor step count not one of two values.	0 (closed) 990 (open)	SD / SDSM	Possible effects on EV radiance or reflectance calibration
7.	SRCA On	If the SRCA is turned on then stray light could affect the blackbody and space view radiance.	NA	SRCA	The effect is currently not known and expected to be small. No contingency.
8.	MODIS DN stability flag under SRCA illumination, DN(B,D)	Averaging over number of scans for each band / channel, a flag will be set if the standard deviation is greater than thresholds. The unstable DN will reduce radiometric calibration accuracy.	3*NEdL	SRCA	Non-correctable.
9.	DN_max_sign $DN_{max}(B,D)$	When the SRCA is illuminating MODIS in radiometric mode, three DNs centered around the maximum value will be averaged. Flag will be set if the standard deviation for the three signals is over the thresholds.	0.5%	SRCA	It protects the DN averaging from using partial illumination data. Non-correctable.
10.	DN saturation flag	If MODIS is greater than a preset saturation DN value, flag will be set in order to exclude the spurious DN in calibration.	4095	SRCA	Non-correctable.
11.	SIS source signal flag, $I_{SIS,SiPD}(t)$, $V_{SIS}(t)$,$I_{SIS}(lamp,t)$	The SRCA feedback SiPD signal needs to be monitored in constant radiance mode while the lamp current and voltage signals need to be monitored in constant current mode. If the values change over a preset range during the radiometric calibration, flag needs to be set indicating that the source is unstable.	TBD	SRCA	Non-correctable.
12.	SIS source temperature flag, $T_{SIS,SiPD}(t)$	The SiPD embedded into the SIS is temperature-controlled. Any abnormal change will vary the SiPD spectral response in constant radiance mode in result of SIS output change.	TBD	SRCA	Non-correctable.
13.	Calibration / reference SiPD dark current	Before and after the SRCA lamps are on in spectral mode, the dark current needs to be averaged over a time. The standard deviation	TBD	SRCA	This is one of the indicator that the spectral calibration is in

	instability flags, $I_{calib}(t)$, $I_{ref}(t)$	provides a check to the instability of the two SiPDs. The averaged dark current is calculated and will be subtracted from the SiPD signals when the lamps are on.			normal operational situation.
14.	SIS source feedback SiPD dead flag	Check if the SiPD current remains at noise level when the lamps are on.	I<1.3*I_dark + 3*sigma	SRCA	This is an indicator that the constant radiance mode fails
15.	SIS source housing temperature flag, $T_{SIS}(t)$	Measure the housing temperature and give warning flag when it passes a given (design) operational temperature range.	TBD	SRCA	Indicator of poor heat sink and may affect lamp output in constant current mode and lamp lifetime
16.	Daytime operation flag	When the SRCA is operating during the daytime that the earth/atmosphere is illuminating MODIS	NA	SRCA	Process this information may provide an estimate of stray-light effect
17.	Reference/calibration SiPD instability flag, $DN_{ref}(step,m)$, $DN_{calib}(step,m)$	Three reference/calibration signals are available per scan. Calculate the standard deviation.	TBD	SRCA	Indicating the signal stability of reference SiPD in spectral calibration.
18.	Calibration/reference SiPDs overwarming flag, $T_{SRCA}(t)$	Temperature correction will be introduced to the two SiPD responsivities. If the temperature is beyond the correctable range, the correction will be inaccurate.	TBD	SRCA	Affect responsivity correction for the temperature change.
19.	SV coherent noise (B,D)	Significant power spectral peak in SV. Based on averaged spectra of normalized SV buffer counts in reflective bands	$\frac{\{\max(\bar{I}_p)\}}{\sigma_X^2} \geq \chi^2(2M)$ M:SV scans in granule $\bar{I}_p$:means of spectral estimates	SV	Cyclical noise signal contaminates background offset data. Possible bias in offset correction.
20.	SV outlier maximum (B,D)	Number of rejected SV values in current SV scan exceeds preset limit.	6	SV	Offset correction weighted more strongly by previous/future SV scans.

21.	SV mirror side difference (B,D)	Difference of SV DNs from both scan mirror sides fell outside predetermined confidence interval.		SV	Effective DN algorithm not accounting for mirror side reflectances
22.	Moon in SV	Moon within a predetermined angular distance from the SV port.	θ_{moon}	SV	SV data cannot be used for offset correction. Use previous statistics of SV buffer for offset correction.
23.	High Intra Granule Space View Voltage Rise	Suspicious rise or fall of space view voltage inside current 3 granules not due to ordinary thermal drift.	Pending analysis of PFM data	SV	Indicative of moon coming in space view, sun coming in solar diffuser, or other vicarious effects.
24.	Arithmetic error while calculating calibration coefficients (B,D)	A division by zero, square root of a negative number, or similar problem was detected while calculating a calibration coefficient that applies to all the values in a scan line.	NA	SW	
25.	A&E Mode Error Estimates	During the Activation and Evaluation period at the beginning of the MODIS mission the uncertainty estimates are set to 100% of the corresponding radiance or reflectance.	NA	SW	Special care should be used when interpreting data taken during this period.
26.	Linear Calibration	The L1B radiometric product is determined with a linear equation.		SW	
27.	Detector Set Point Drift	Detector temperature not at expected set point value(s)	0.1K	Thermal	
28.	DC Restore Failure	If the DC restore data is not in the telemetry then the baseline algorithm cannot be used.	NA	Thermal	Contingency: Linear Calibration or Delta DN Algorithm.
29.	DC Restore Performed Locally	The DC restore electronics have been adjusted on one of the primary scans used by the calibration algorithm. Locally means within 35 scans of current scan (includes preceding and	NA	Thermal	

		succeeding scans).			
30.	Blackbody / Cavity Temperature Differential.	High differential between blackbody and cavity temperature based on radiometric effects due to limited blackbody emissivity knowledge. $\sqrt{\left(T_{cav} - T_{bb}\right)^2} \geq Threshold$ (TBR)	5K	Thermal	
31.	Blackbody Heater On	Heater unit of the blackbody is on.	NA	Thermal	
32.	Bad blackbody thermistor(s)	Too many blackbody thermistors are rejected as outliers.	>4	Thermal	
33.	Blackbody Signal Outliers	Too many blackbody digital counts are rejected as outliers.	>6	Thermal	
34.	Bad thermistors	One or more of a list of thermistor measurements critical to the thermal algorithm are declared bad or missing.	NA	Thermal	
35.	High Intra Granule Blackbody Voltage Rise	Suspicious rise or fall of FPA voltages while viewing the BB inside current 3 granules not due to ordinary thermal drift.	Pending analysis of PFM data	Thermal	Indicative of moon coming in space view, sun coming in solar diffuser, or other vicarious effects.
36.	Csub Performed Locally	Charge subtraction occurred locally.	NA	Thermal	
37.	Nonuniform blackbody heating	Thermistors centered around one heater deviate from thermistors centered around other heated by more than 0.05K.	0.05K	Thermal	
38.	Csub Current or Next Scan	Charge subtraction occur on the current or next scan	NA	Thermal	
39.	Earth View Sun Shield Hot	Earth View Sun Shield is too high	315K	Thermal	
40.	Space View Housing Hot	SAM temperature is too high	300K	Thermal	
41.	DC Restore Performed	The DC restore electronics have been adjusted on the current or next	NA	Thermal	

	Current or Next Scan	scan			
42.	Marginal Thermal Gain	Marginal number of scans used in thermal gain measurement	<35 scans	Thermal	
43.	Marginal Thermal Offset	Marginal number of scans used in thermal offset measurement	<10 scans	Thermal	
44.	Current Scan Noise	Current scan not used for noise reduction	NA	Thermal	
45.	Next Scan Noise	Next scan not used for noise reduction	NA	Thermal	

B: MODIS band (1-36)

D: Detector (1-40, 1-20, 1-10)

7.2.2. QA Flags for the L1B SRCA Cross Granule Product

Table 6 SRCA Cross-Granule QA Flags

#	Flag Name	Description	Threshold	Algorithm	Impact
1.	MODIS DN change flag, DN(b#,ch#)	If MODIS DN change is greater than threshold, set a flag	1.5% of the prelaunch values in radio-metric mode during A&E	SRCA	Warning that MODIS responsivity may have changed and further correction may be needed
2.	ND filter transmittance change flag, τ(b#)	Using the ratio of DN with ND to DN without ND in radiometric mode to detect possible ND transmittance change on-orbit	TBD	SRCA	Correction for ND transmittance may be considered in radiometric transfer
3.	Saturated calibration / reference SiPD flag, DN_{ref}(step,m), DN_{calib}(step,m)		4095	SRCA	indicating that the spectral calibration accuracy may be affected
4.	Dead		I_max<1.	SRCA	Spectral

	calibration / reference SiPD flag		3(I_dark + 3sigma)		calibration / radiometric transfer will fail.
5.	Order-sorting filter position malfunction flag, DN_{ref}(step,m), DN_{calib}(step,m), MSR(step,m)	Order-sorting filter position signal needs to be provide with spectral signal in spectral mode	NA	SRCA	Ensure that the spectral signals of reference / calibration SiPDs and MODIS is properly obtained.
6.	Malfunction flag for the SRCA monochromato r parameters, β(L) and θ_{off}(L)	The SRCA spectral mode will provide two monochromator parameters: β and θ_{off}. These two parameters have an operational range. If spectral calibration results show that the two parameters are off the range, the calibration results are questionable.	TBD	SRCA	Provide reliability information of the spectral calibration.
7.	Malfunction flag for the focal plane assembly (FPA) shift, X(FPA), Y(FPA), θ(FPA), M(FPA)	FPA shifts, shift along scan, shift along track, rotation, and magnification change, will be calculated based upon the information of detector, band shifts. The shifts should be in a reasonable range where the FPA can be located.	TBD	SRCA	Provide reliability information of the spatial calibration

b#: MODIS band number (1-36)

ch#: Channel number (1-40, 1-20, 1-10)

7.2.3. QA Flags for the L1B SD/SDSM Cross Granule Product

Table 7 SD/SDSM Cross-Granule QA Flags for Reflective Bands

#	Flag Name	Description	Threshold	Algorithm	Impact
1.	SD outlier maximum (B,D)	Number of rejected SD values in current SD scan exceeds preset limit.	≥ 10	SD / SDSM	Estimate of receives little weight from mean SD data of current scan
2.	SDSM outlier detected (b,s)	SDSM sample rejected as outlier.	≥ 2	SD / SDSM	Estimate of Δ(b) receives no weight from sample s.
3.	SDSM saturation (b)	SDSM A / D saturation during current solar	≥ 2	SD / SDSM	Estimate of Δ(b) unavailable. Use value

		calibration period.			of last solar cal. period.
4.	Low SDSM SNR (b)	SDSM detector SNR fell below threshold.	< 100	SD / SDSM	Estimate of $\Delta(b)$ has larger uncertainty.
5.	SDSM dead detector(b)	SDSM count below threshold for sun or SD sampling during current solar ca. period.	< 200	SD / SDSM	Estimate of $\Delta(b)$ unavailable. Use value of last solar cal. period.
6.	SDS transmittance changed	SD screen transmittance changed since last estimate was calculated.	$> 1\%$	SD / SDSM	Obtain new estimate of SD screen transmittance.
7.	SDSM angular response change	SDSM angular response during last solar cal. period fell outside predetermined confidence interval	SDSM characteriza tion: PFM and in-orbit	SD / SDSM	Obtain new estimate of SDSM angular response, and use in cross-granule processing.
8.	Bad SDSM mirror step count	SDSM mirror motor step count at SD, Sun, or DCR improper.	0 (SD) 29 (DCR) 58 (Sun)	SD / SDSM	τ_{SDSM} may need adjustment to account for improper mirror angle during Sun sampling. Possible bias in offset correction and / or SD samples.
9.	Responsivity goodness of fit (B,D)	R^2 for goodness-of-fit of SD counts vs. SD radiance fell outside predetermined confidence interval.	$R^2 \leq 0.9$ (nominal) PFM	SD / SDSM	Possible non-linearity and / or noisy detectors.
10.	Responsivity intercept (B,D)	F-test rejects null hypothesis that intercept of straight-line fit of counts vs. SD radiance is zero.	Test H_0 at 5% level	SD / SDSM	Possible non-linearity and / or noisy detectors.
11.	Responsivity outlier (B,D)	Responsivity estimate fell outside prediction band.	Test H_0 at 5% level	SD / SDSM	Several causes. Flag initiates a TLCF analysis.

B: MODIS band (1-19, 36)

b: SDSM band (1-9)

D: Detector (1-40, 1-20, 1-10)

S: MODIS scan mirror scan number (1-2)

s: SDSM sample number

7.3. Acronym List

A/D	Analog to Digital
A&E	Activation and Evaluation
BSDF	Bidirectional Scattering Distribution Function
DAAC	Distributed Active Archive Center
DCR	Direct Current Restore
DN	Digital Number
EV	Earth View
L1A	Level 1A
L1B	Level 1B
LUT	Lookup Table
MODIS	Moderate Resolution Imaging Spectroradiometer
OBC	On-Board Calibrator
SBRS	Santa Barbara Remote Sensing
SDP	Science Data Production
SD	Solar Diffuser
SDSM	Solar Diffuser Stability Monitor
SIS-100	Spherical Integrating Source - 100 cm
SRCA	Spectroradiometric Calibration Assembly
SV	Space View
TLCF	Team Leader's Computing Facility

7.4. Glossary

Channel	Think of it as the data from one MODIS detector. If you deal with bands 13 or 14 we have to be more precise, but the channel-detector association works for the rest of the MODIS bands. For bands 13 and 14 we use Time Delay Integration and dual gains so that two detectors in each band become linearly composed into two channels in each band at each 1km spot in the Earth View. Yes, it is confusing. Ask MCST for more information if you want it.
Effective DN	Instrument DN corrected for the effects of temperature, scan mirror scatter, scan mirror reflectance, and digitizer quantization non-linearity
Frame	The elemental unit of MODIS data associated with the scan sector. Synonymous with pixel.
Granule	A collection of MODIS scans, nominally 100.
Level 2	Data products derived from the L1B data product.
Scan	The collection of data frames associated with a half rotation of the scan mirror. In the Earth View data sector it is 10km wide.
Scan Line	The collection of frames associated with a single channel within a scan. It may be 250m, 500m, or 1km wide in the Earth View.